OFFICE OF THE DIRECTOR OF NATIONAL INTELLIGENCE

Standoff Iluminator for Measuring Absorbance and Reflectance Infrared Light Signatures (SILMARILS)

Office of Smart Collection

Proposers' Day Brief – Kristy DeWitt

20 January 2015

Agenda

Time	Topic	Speaker
8:15am – 8:30am	IARPA Overview and Remarks	Dr. Ed Baranoski SC Office Director
8:30am – 9:30am	SILMARILS Program Overview	Dr. Kristy DeWitt Program Manager
9:30am – 10:00 am	BAA Overview, T&E, GFI/GFE	Dr. Kristy DeWitt Program Manager
10:00am – 10:30am	Break – View Posters	
10:30am – 11:00am	Doing Business with IARPA	IARPA Acquisition
11:00am – 11:30am	SILMARILS Program Questions & Answers	Dr. Kristy Dewitt Program Manager
11:30am – 12:30pm	Lunch – View Posters	
12:30pm – 2:00pm	Proposers' 5-minute Capability Presentations	Attendees (**No Government**)
2:00pm – 3:00pm	Proposers’ Networking and Teaming Discussions	Attendees (**No Government**)

SILMARILS Program Overview

The Problem

- IC needs:
  - Non-contact, discreet screening of people and vehicles
  - Standoff detection/identification of target chemicals in hard-to-access areas
  - Rapid indoor/outdoor forensic scene analysis
- Current state of the art for positive chemical ID of trace surface residue requires direct contact
- Existing standoff techniques limited by:
  - Sensitivity/specificity/performance in real-world clutter
  - Safety/observability issues which limit CONOPS
  - Interrogation time/areal coverage

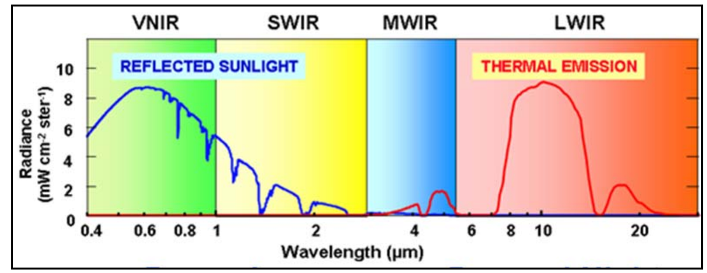
How is Standoff Detection Done Now?

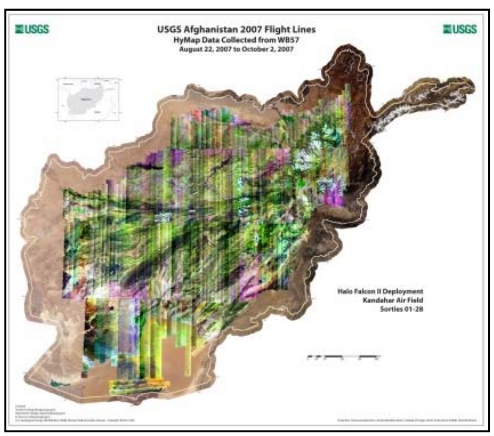
- All true standoff detection uses optical techniques

- Passive illumination
  - Hyperspectral imaging (HSI)
- Active illumination
  - Fluorescence
  - Differential Absorption LIDAR (DIAL)
  - Raman Scattering
  - Laser Induced Breakdown Spectroscopy (LIBS)

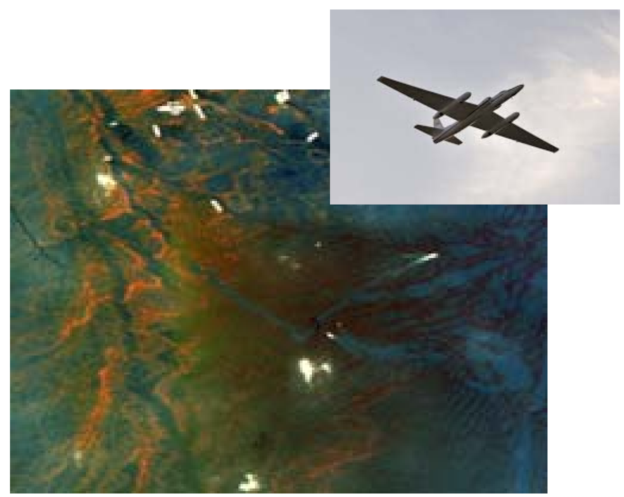
Current Standoff Detection: Passive HSI

- Ambient light/thermal emission as source, record spectrum at each image pixel
  - Dispersive spectrometer: typically 128-256 bins across spectrum, 20-50 cm^{-1} resolution
- Recent successful demonstrations of chemical ID in theater from aerial platforms w/ high clutter
- Limitations:
  - Limited sensitivity due to SNR/resolution trade-off requires at least 3-10% of surface area to be covered by the target chemical (mg/cm^2 to g/cm^2)
  - Affected by illumination irregularities



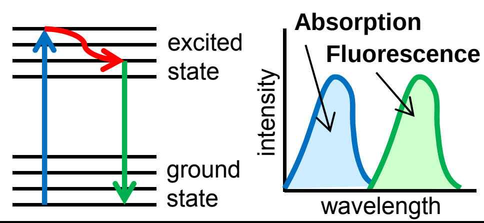
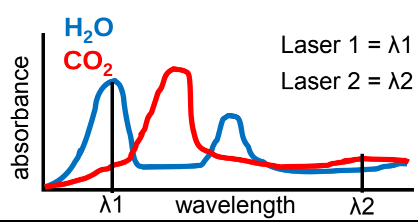
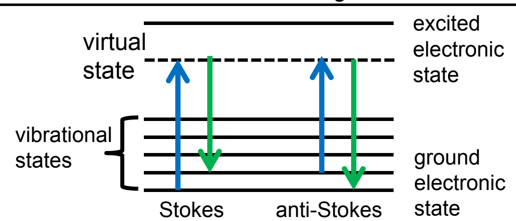
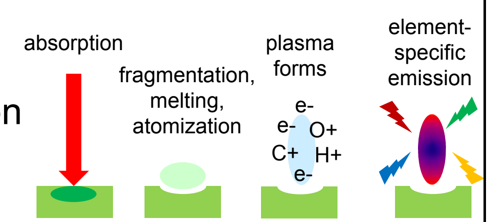


USGS mineral mapping of Afghanistan with HyMap SWIR HSI sensor to support crop options other than the poppy



NASA ER-2 platform flying AVARIS sensor to map spread and characteristics of Deepwater Horizon oil spill

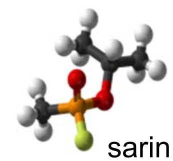
Types of Standoff Detection: Active Illumination

Method	How it Works	Limitations	Examples
Fluorescence	• UV/visible pump, detect red-shifted emission 	• Gas-phase only • Low specificity b/c of broad ro-vibronic excitation	• Bio-detection cueing sensor in JPEO fielded system
DIAL (Differential Absorption LIDAR)	• Ratio on/off resonance laser λ's to detect target 	• Gas-phase only • Low specificity b/c of limited bandwidth	• NASA LASE: ER-2 platform • Future development
Raman Scattering	• Off-resonance inelastic scattering 	• Sensitivity limited b/c off resonance (10^6 lower direct absorption)	• DTRA: CARDS • DHS: VEST • DARPA: LUSTER
LIBS (Laser Induced Breakdown Spectroscopy)	• Laser ionization, record emission spectrum of excited ions 	• Sensitivity limited b/c of high power density needed for ionization	• DARPA: RIEDAR • MIT/LL: BAWS

Increasing power, decreasing standoff

SILMARILS: What, Why, and How

- Stand-off (30+ m) detection and identification of target chemicals in clutter
- Compound classes of interest:
  - Primary:
    - Explosives (TNT, RDX, AP)
    - Chemical weapons/poisons (sarin, hydrogen cyanide, NTAs)
    - Narcotics (cocaine, heroin, Vicodin)
  - Compounds associated with manufacture/deployment of biological agents & nuclear material

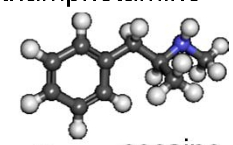


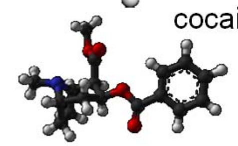
sarin

hydrogen cyanide

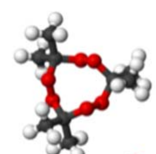
- Goal: Active infrared spectroscopy to enable lab-quality ID of trace chemical residues on surfaces with mission relevant sensitivities and real-world clutter
  - High area scan rate, portable, eye-safe, use with uncooperative/ unaware subjects

methamphetamine

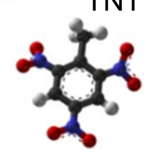




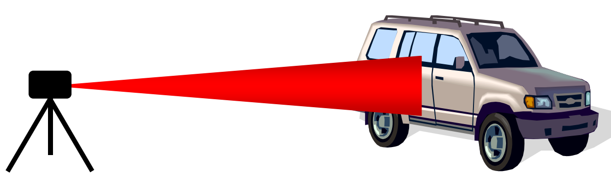
cocaine



AP



TNT



Key Program Drivers

Known

- Existing passive hyperspectral imaging can ID chemicals in cluttered environment, but not yet at required mission sensitivity levels
- Basic physics of active IR absorbance at the needed sensitivity levels are well developed for laboratory environments

Enabling Developments

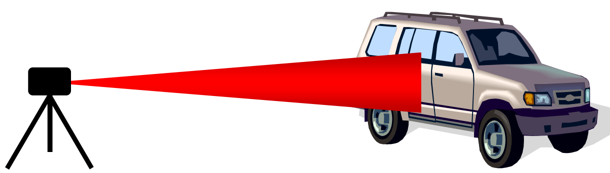
- Optical sources & detectors to bring lab techniques to the field are near TRL 3
- Expansive spectral libraries of targets, background, confuser signatures exist (80,000+ signatures to date)
- Algorithms and physical models adaptable from passive hyperspectral, Raman, other active techniques

Program Concept

- Tailored algorithms and specific background/clutter filter approaches
- Full understanding of surface/particle effects
- Optical train design from component technology
- Prototype for field testing

End-of-Program Goal

- Prototype portable scanner for field forensics with 30+ m standoff range
- High sensitivity & specificity, eye safe, works with complex mixtures
- “Large shoe-box” size, grid power or ~1 hour battery operation
- Scan time: 1 m^2 in 15 s at 30 m and 10 cm^2 @ 60 Hz at 5 m



vehicle scan CONOPS

Gas	Solution	Solid/Liquid
0.1 ppm	10 μg/mL	1 μg, 0.1 μ/cm^2

Example SILMARILS Applications

Scan human hands, shoes, clothing for explosives & narcotics @ airport security

Has car trunk previously transported cocaine?

Detect invisible meth residue on counter in suspected former lab site

Detect explosive residue in fingerprints on car door in parking garage or approaching checkpoint

What is this white powder?

Screening of stationary vehicle or cargo

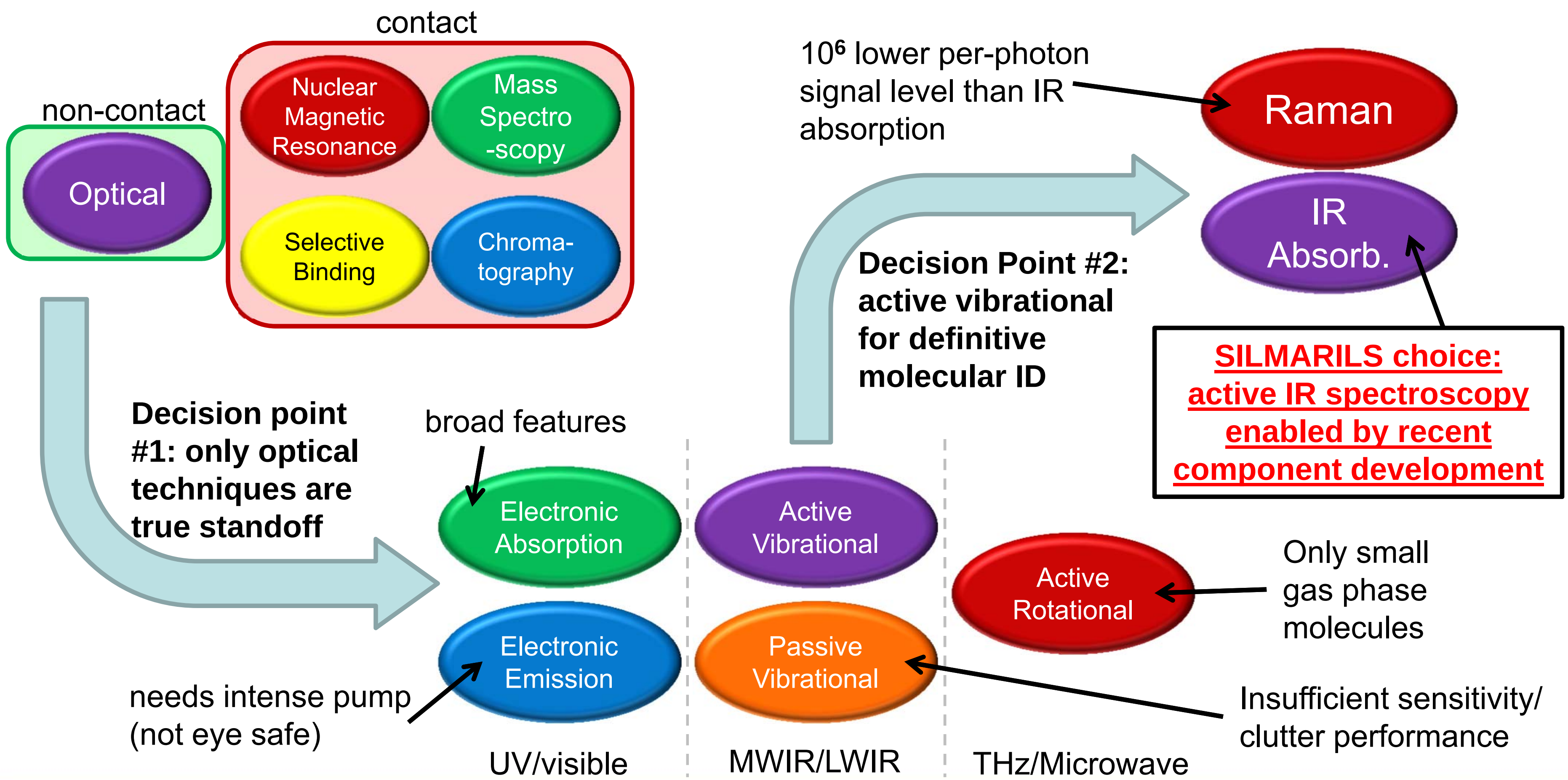
Forensic analysis of pavement in area of suspected chemical release

What is the Best Approach to Standoff Chemical Detection?

- Set aside history and start from first principles
  - Imagine taking a virtual tour of a forensic chemistry laboratory – are any of the “gold standard” laboratory analytical techniques adaptable?

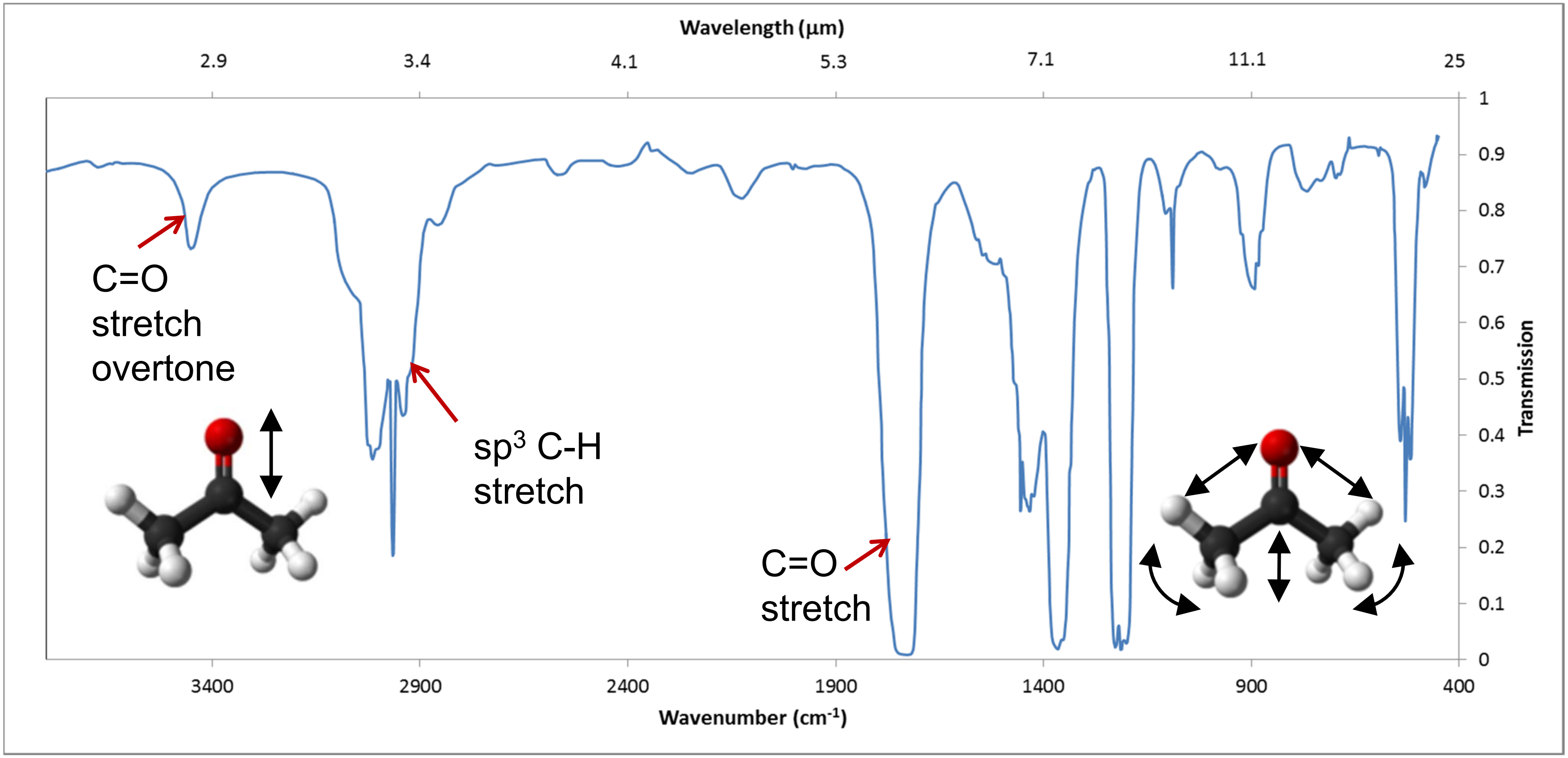
- Goals:
  - Standoff
  - High sensitivity & specificity
  - Eye safe
  - Works with complex mixtures

Developing an Approach: Start at the Beginning



IR Spectrum Provides Molecular Barcode

Acetone IR Spectrum – Neat Liquid



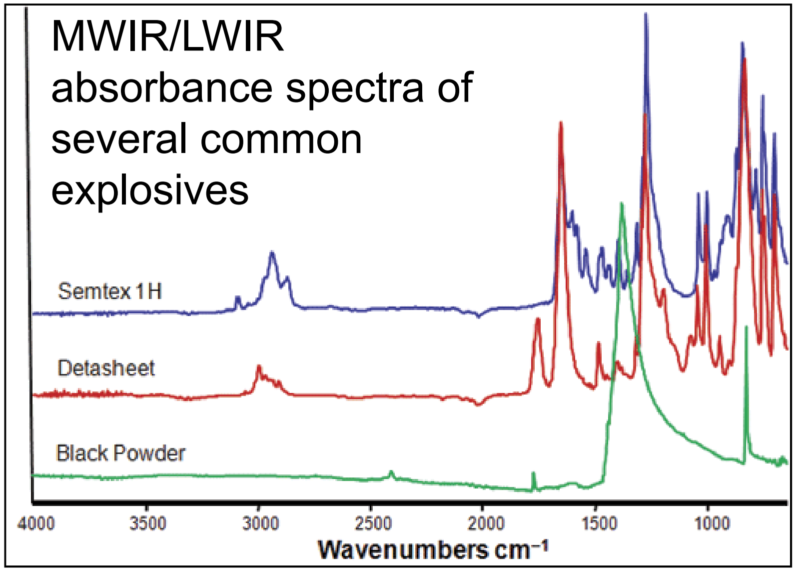
MWIR – "functional group" region: Bending and stretching motions of a few directly connected atoms

LWIR – "fingerprint" region: Twisting, rocking, breathing modes of whole molecule

IR Sensitivity vs. Mission Needs

- Standard laboratory optical capability is 10-100X higher than most mission needs
- SILMARILS will extend lab level performance to standoff

Representative Targets	Mission-Relevant Concentration*	Lab Optical*
Explosives		
RDX (print)	4 mg – 1st print 100 ng – 10th print 14 ng – 50th print	1 µg
TNT (fallout)	0.1 µg/cm^2	1 µg
Toxic Chemicals		
GA, GB	5.1 µg/cm^2 (liquid)	1 µg
HD	1.0 µg/cm^2 (liquid)	1 µg
H_2S	0.7 ppm (gas)	0.05 ppm
NH_3	30 ppm (gas)	0.05 ppm
Narcotics		
Cocaine (saliva)	500 µg/mL	10 µg/mL



SILMARILS Goal	Gas	Solution	Solid/Liquid
	0.1 ppm	10 µg/mL	1 µg, 0.1 µg/cm^2

So if IR is So Great, Why are There No Fielded Systems? Part 1: The Spectrometer

- Current active IR techniques limited by sources & detectors
  - Broadband incoherent light sources require large optics, have limited range
  - Narrow-band coherent sources limit spectral coverage & therefore specificity
  - Spectrometer-based detection trades SNR, resolution, scan speed

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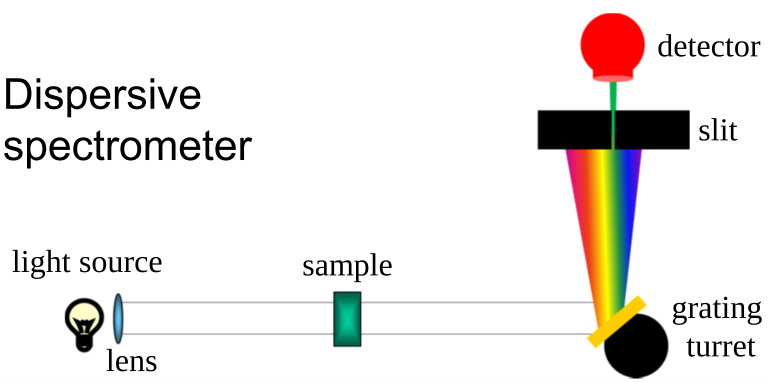
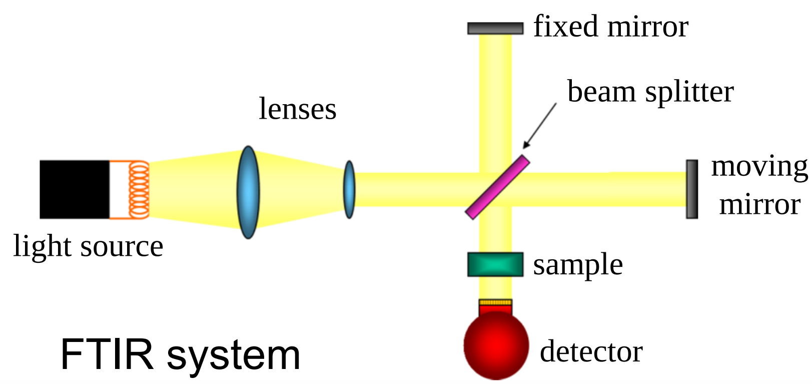
- Laboratory IR spectroscopy history: shift from dispersive to FTIR systems
  - 50 years ago: dispersive IR spectrometers trade off SNR, resolution, scan speed
  - Today: FTIR systems enable simultaneous high throughput, sensitivity and resolution, as well as simplify detection optics

Dispersive spectrometer



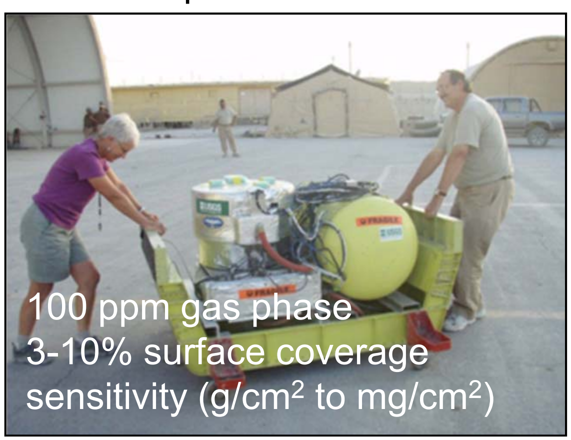


FTIR system

New Approach: Broadband Coherent Sources & Interferometric Spectroscopy

- SILMARILS program will use a similar paradigm-shifting approach to bring the capability of laboratory IR spectroscopy to the field
- Key requirements:
  - Broadband source with high brightness and spatial uniformity
  - Sufficient transmitted power above thermal background while remaining eye-safe
  - Improved detection: interferometric approaches allow use of monochrome point & array detectors, eliminating spectrometers increases SNR/resolution & reduces moving parts

Current passive HSI sensor

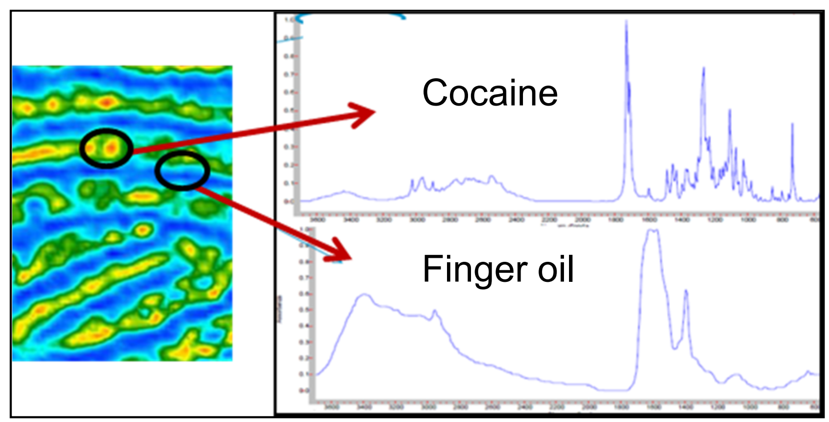


Gas	Solution	Solid/Liquid
0.1 ppm	10 µg/mL	1 µg, 0.1 µ/cm^2

Part 2: IR Spectroscopy in the Real World

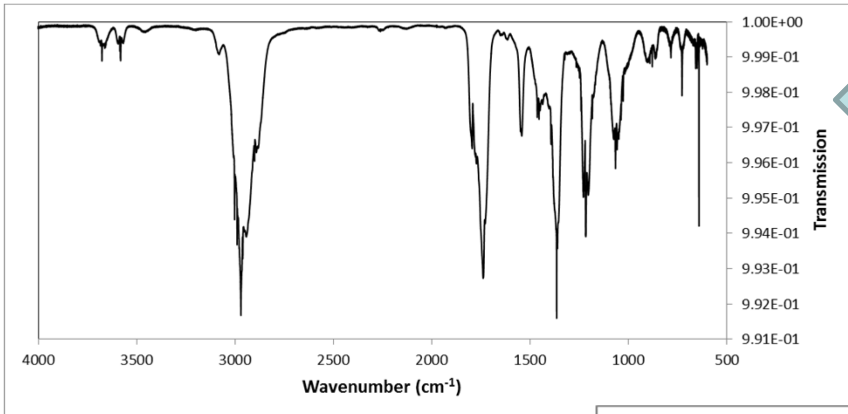
- Target signatures must be distinguishable from spectral features belonging to other compounds in same sample area
  - No atomically clean surfaces or evacuated gas cells
- Signal-to-clutter ratio more important to detection threshold than signal-to-noise
- To be useful in the real world SILMARILS must:
  - Incorporate comprehensive signature library: targets & relevant background compounds
  - Account for differences in absorption band shape & intensity: depends on particulate size, illumination angle, polarization, humidity, etc.
  - Exploit sampling methods and spectral features to develop real-time chemical ID algorithms with high sensitivity & specificity for targets in a cluttered environment

Representative Discrimination Example



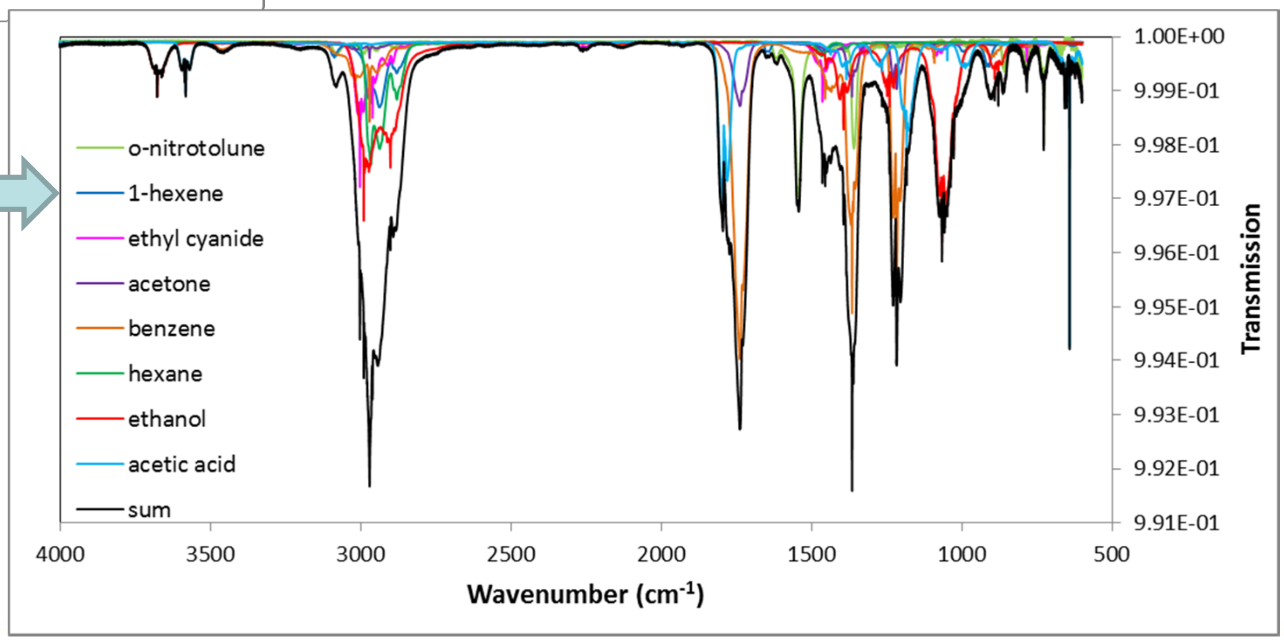
FTIR microscopy of a fingerprint shows traces of cocaine residue clearly distinguishable from finger oil

Complex Spectrum Example



Raw transmission spectrum of nine gas phase chemical species at ~ equal concentration

Principal components analysis showing contribution of each species to total spectrum



Composite spectra simulated from individual literature spectra

Key Enabling Technologies

- Component advances in the past 5-7 years provide building blocks to make SILMARILS possible now

Spectroscopy
- Algorithms
- Spectral Signatures
- Physical Model

Spectrometer
- Sources
- Detectors
- Fiber Components

- For success, need to focus on the system as a whole & emphasize real-word sample conditions

Representative Technology Components for Spectrometer Development

Technology Components	Examples
Sources	• Fiber-based comb sources • Chip-scale comb sources • Quantum cascade lasers (tunable & fiber coupled arrays) • Fiber-based supercontinuum sources
Detectors	• TEC-cooled HgCdTe single element & array detectors • Uncooled microbolometer element & array detectors • Integrated digital background subtraction to leverage pulse sources
Optical/Photonic Components	• Photonic crystal fiber for supercontinuum generation, dispersion control • Crystal-core, glass clad fiber for laser gain medium and/or nonlinear optical conversion • Piezo fiber stretcher • IR GRIN lenses

Algorithm Development

- Take advantage of existing methods & software from similar problem sets, but recognize differences/limitations
  - Radar processing
  - Passive hyperspectral
- Tailor standard analysis techniques for signal-to-clutter limited environments
  - Derivative spectra
  - Cross correlation
  - Matched filter
  - Principal components analysis

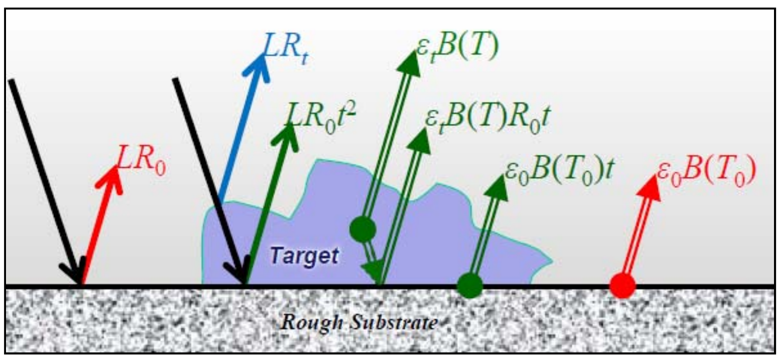
Name	Formula	T	B	Signal Model	Comments
RX Anomaly Detector	$\mathbf{x}^T\Sigma_b^{-1}\mathbf{x}$ $\mathbf{x} \leftarrow \mathbf{x} - \mu_b$	None	μ_b Σ_b	$H_0 : \mathbf{x} \sim N(\mu_b, \Sigma_b)$	GLRT
Quadratic Detector	$(\mathbf{x}-\mathbf{s})^T\Sigma_t^{-1}(\mathbf{x}-\mathbf{s}) - \mathbf{x}^T\Sigma_b^{-1}\mathbf{x}$ $\mathbf{s} = \mu_t - \mu_b$	$\mathbf{s}$ Σ_t		$H_1 : \mathbf{x} \sim N(\mu_t, \Sigma_t)$	LRT
Matched Filter	$\mathbf{s}^T\Sigma_b^{-1}\mathbf{x}$	$\mathbf{s}$		$\Sigma_t = \Sigma_b$ $\mathbf{x} = a\mathbf{s} + \mathbf{v},\ a > 0$	LRT max SCR
ACE	$\dfrac{\left(\mathbf{s}^T\Sigma_b^{-1}\mathbf{x}\right)^2}{\left(\mathbf{s}^T\Sigma_b^{-1}\mathbf{s}\right)\left(\mathbf{x}^T\Sigma_b^{-1}\mathbf{x}\right)}$			$\mathbf{x} = a\mathbf{s} + \beta\mathbf{v}$ $\mathbf{v} \sim N(\mathbf{0}, \Sigma_b)$	GLRT Scale invariant CFAR
Subspace T MF	$\mathbf{x}^T\Sigma_b^{-1}\mathbf{S}\left(\mathbf{S}^T\Sigma_b^{-1}\mathbf{S}\right)^{-1}\mathbf{S}^T\Sigma_b^{-1}\mathbf{x}$	$\mathbf{S}$		$\mathbf{x} = \mathbf{Sa} + \mathbf{v}$	GLRT
Subspace T ACE	$\dfrac{\mathbf{x}^T\Sigma_b^{-1}\mathbf{S}\left(\mathbf{S}^T\Sigma_b^{-1}\mathbf{S}\right)^{-1}\mathbf{S}^T\Sigma_b^{-1}\mathbf{x}}{\mathbf{x}^T\Sigma_b^{-1}\mathbf{x}}$			$\mathbf{x} = \mathbf{Sa} + \beta\mathbf{v}$	GLRT Scale invariant CFAR
Subspace T & B Detector	$\dfrac{\mathbf{x}^T\mathbf{P}_B^{\perp}\mathbf{x}}{\mathbf{x}^T\mathbf{P}_{BS}^{\perp}\mathbf{x}}$ Full pixel $\Rightarrow \mathbf{P}_{BS}^{\perp} = \mathbf{P}_S^{\perp}$		$\mathbf{B}$	$\mathbf{x} = \mathbf{Sa} + \mathbf{Ba}_b + \mathbf{w}$ $\mathbf{w} \sim N(\mathbf{0}, \sigma_w^2\mathbf{I})$	GLRT CFAR

Radar-developed algorithms in current use for hyperspectral image analysis

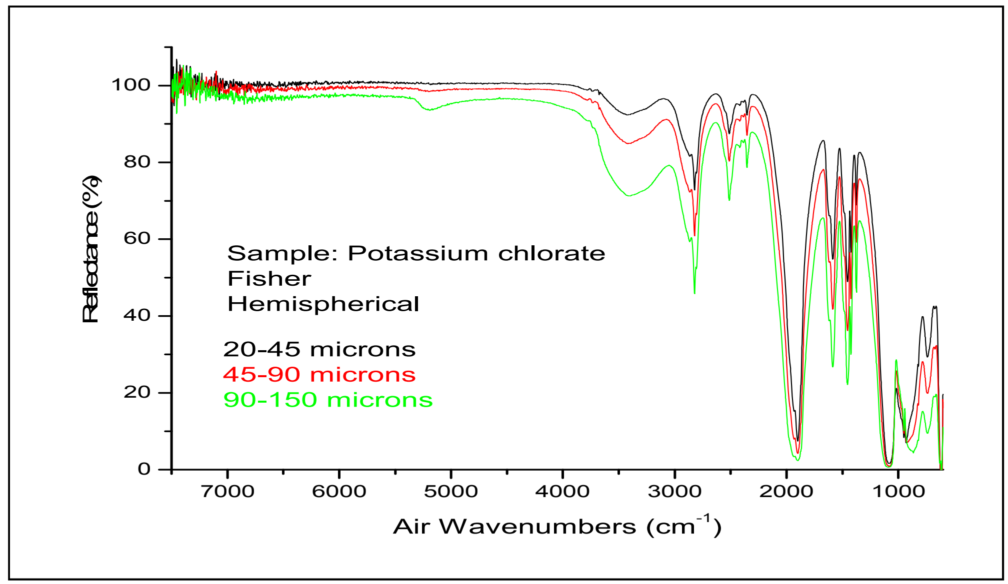
- Use prior information and exploit the measurement process to simplify processing & improve sensitivity/specificity
  - Filter chemical classes in/out of dynamic search library based on MWIR peaks
  - Exploit spatial inhomogeneity via differential spectroscopy
  - Ultra-high resolution spectra facilitate background gas removal

Physical Model / Environmental Influences

- Must account for spectral changes due to reflectance/absorption partitioning, incidence angle, substrate types, polarization
  - Multiple signature measurements for single compound
  - Semi-empirical model/extrapolation
  - "Squishy" fits



Semi-empirical rough surface physical model parameter set



Effect of particle size on absolute and relative band intensity for $KClO_3$

Recap

Known

- Existing passive hyperspectral imaging can ID chemicals in cluttered environment, but not yet at required mission sensitivity levels
- Basic physics of active IR absorbance at the needed sensitivity levels are well developed for laboratory environments

Enabling Developments

- Optical sources & detectors to bring lab techniques to the field are near TRL 3
- Expansive spectral libraries of targets, background, confuser signatures exist (80,000+ signatures to date)
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Program Concept

- Tailored algorithms and specific background/clutter filter approaches
- Full understanding of surface/particle effects
- Optical train design from component technology
- Prototype for field testing

BAA Overview, T&E, GFI/GFE

Goals

- Develop a prototype portable system for standoff (30+ meter) detection and identification of trace chemical residues on surfaces using active infrared spectroscopy
  - High chemical sensitivity and specificity across a broad range of target classes
  - Effective operation in a real world environment
  - System is eye-safe and suitable for use with uncooperative/unaware subjects
  - "Large shoe box" size & ~1 hour battery operation
  - Reasonable scan rate

Program Structure Overview

Item	Phase 1	Phase 2	Phase 3
Duration	18 months	18 months	18 months
Scope	Algorithms: Test against Government provided data set. Spectrometer: Laboratory breadboard traceable to Phase 3 design. Performance demonstration against standard samples representative of real-world background/ clutter.	Spectrometer components near final SWAP, but system still laboratory breadboard. Integration of spectrometer and algorithms with non real-time processing. Incorporate new spectroscopy/sample methods to improve sensitivity/specificity.	Prototype field demonstration with real-time processing (both spectral reconstruction and chemical detection/ identification). Training package for Government/ contractor operation.

BAA Highlights

- Single BAA for all phases (Base and two Option periods)
- Offeror team must address all of program requirements, no partial proposals, such as development of specific component technology, will be accepted
- The Government anticipates that proposals submitted under this BAA will be unclassified
- Multiple awards expected
- Foreign participants and/or individuals may participate to the extent that such participants comply with any necessary Non-Disclosure Agreements, Security Regulations, Export Control Laws and other governing statutes applicable under the circumstances
- Option award based on performance against Milestones, mission needs, availability of funds

Metrics – Part 1

Metric	Milestone 1 Phase 1	Milestone 2 Phase 2	Milestone 3 Phase 3
Sensitivity (clean sample)	Surface: 0.1 μg/cm^2, 1 μg absolute Gas Phase: 0.1 ppm	Surface: 0.1 μg/cm^2, 1 μg absolute Gas Phase: 0.1 ppm	Surface: 0.1 μg/cm^2, 1 μg absolute Gas Phase: 0.1 ppm Solution: 10 μg/mL
Specificity (must identify all components)	Individual chemicals & 3-5 component mixtures (10% minimum level for each component)	5-10 component mixtures (1% minimum level for each component)	5-10 component mixtures (1% minimum level for each component)
Clutter (positive ID of target(s) only)	Single target at 1% background level, 3 substrate types, background 10+ compounds	Single target at 0.1% background level and 3 mixed targets at 1% background level each, 5 substrate types, background 15+ compounds	Single target at 0.1% background level and 3 mixed targets at 1% background level each, 7 substrate types, background 15+ compounds
P_d/P_f	>90%/<1%	>95%/<0.1%	>95%/<0.01%
Library	50 targets, 500 background, 10 potential true unknowns	50 targets, 1000 background, 50 potential true unknowns	50 targets, 1500 background, 150 potential true unknowns
Standoff	Traceable to Phase 3 design	Traceable to Phase 3 design	30 m

Metrics – Part 2

Metric	Milestone 1 Phase 1	Milestone 2 Phase 2	Milestone 3 Phase 3
Scan Rate	Traceable to Phase 3 design	Traceable to Phase 3 design	Long range: 1 m^2 scan area @ 30 m, 15 sec report. Short range: 10 cm^2 scan area @ 5 m, 60 Hz update rate
Form Factor (SWAP)	Laboratory breadboard, design traceable to Phase 3	Laboratory breadboard with components near final SWAP	Packaged field prototype Size: > 0.06 m^3 / 2.25 ft^3 (approx. 18”x18”x12”) Weight: > 22 kg / 50 lb Power: 1 hour battery life, Threshold: car battery class; Goal: RC plane class
Safety	Traceable to Class 1 operation at standoff in Phase 3	Traceable to Class 1 operation at standoff in Phase 3	Class 1 at device output aperture. Interlocked to prevent > Class 1 laser exposure if cover removed.
Operation	Operated by Performer expert personnel	End of phase testing by Government or contractor expert personnel.	End of phase testing by Government or contractor expert personnel. Training package to allow additional performance testing by non-expert Government or contractor personnel.
Spectral Coverage	Approach must not result in emission of light visible to the naked eye. Otherwise, choice of spectral coverage left to offerors (trade sensitivity/specificity vs. system complexity). Use of multiple sources to provide required spectral coverage is allowed.		

Milestones and Waypoints

- Milestones are Government-defined progress metrics that must be met by the end of each phase
- Waypoints are offeror-defined, task-driven intermediate steps towards a milestone
  - Depending on an offeror's specific approach, progress towards a milestone is not expected to be linear in all areas
  - Waypoints are how the offeror clearly explains to the Government the quantitative and timely progress that must be made for their overall concept to meet the end-of-phase Milestones – performance against these waypoints is reviewed throughout program
- Technical reviews held at months 5 and 11 in each phase will quantify progress against the waypoints & assess whether course corrections needed for success
- Top-level anticipated Phase 1 performance schedule:

Months after kickoff	5	11	17
Algorithms	Discriminate all single component spectra	Discriminate all mixtures on single substrate	Meet all Phase 1 Milestone metrics
Spectrometer	First light, gas phase transmission spectra	Meet sensitivity metric for pure compounds, start mixture tests	Meet all Phase 1 Milestone metrics

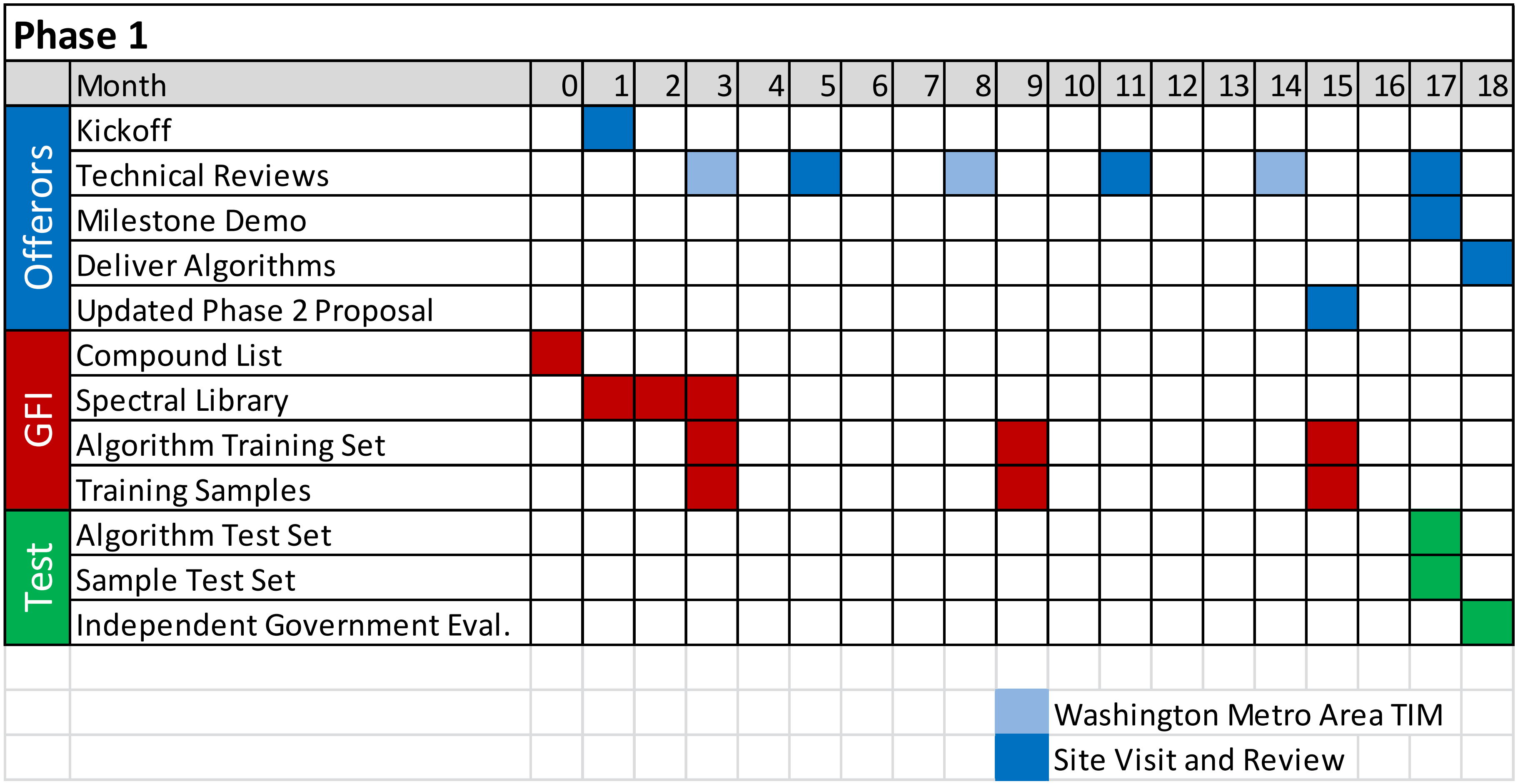
GFI/GFE – Phase 1

- **At Contract Award:** List of target and background chemicals
- **Months 1-3:** "Pure compound" spectral data library
- **Months 3, 9, 15:** Algorithm training sets with full metadata
- **Months 3, 9, 15:** Mixture test samples with full metadata
- Full spectrum toolkit (FSTK) access

T&E/Deliverables – Phase 1

- **Months 5 & 11** – Progress review against offeror-defined waypoints
- **Month 15:** Updated Phase 2 technical details and cost proposal
- **Month 17** – Test algorithms against Government provided mixture spectra
- **Month 17** – Test spectrometer against Government provided pure and mixture samples
- **Month 18** – Deliver algorithms to FSTK

Schedule: Phase 1



Questions?